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MEASURING ACCESSIBILITY AS A SPATIAL INDICATOR OF SPRAWL

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ABSTRACT: *Suburban sprawl has often been identified as low-density and dispersed development that requires greater automobile vehicle miles to be traveled for daily activities thereby resulting in problematic environmental and social impacts. This paper attempts to empirically test one of the spatial characteristics of sprawl by measuring the actual road distance of residential housing units to common every day destinations or "community nodes" in Hunterdon County, NJ. A centroid point is identified for all residential housing units county-wide and the road distance measured to each of the nearest community nodes utilizing a gridded road network approach within a GIS environment. The community nodes included such public activity centers as schools, emergency services, grocery stores, public transit stops, recreational parks, post offices and libraries. The research demonstrates that older compact communities within the county are significantly more accessible to community nodes than much of the more recent housing development providing substantive evidence of the link between sprawl and accessibility. The methodology demonstrates a means of objectively quantifying and comparing new urban development patterns for characteristics of sprawl versus smart growth.*

INTRODUCTION

The term *urban sprawl* has a decades-long history in the academic discourse and yet there is surprisingly no commonly agreed upon definition of what exactly constitutes urban sprawl. There is a need for better defining the term sprawl in order to focus specifically on the undesirable and problematic characteristics of development that many stakeholders argue should be avoided. By focusing on specific problematic traits associated to sprawl, a set of empirically measurable indicators can provide a means of grading how well a particular development performs for a specific undesirable characteristic. This paper develops a metric for distinguishing urban sprawl from non-sprawl urban development through the measurement of road accessibility to a set of common community destinations at the scale of an individual housing unit.

BACKGROUND

There has been a range of approaches to the analysis of certain aspects of sprawl, but most have focused on socioeconomic factors that utilize census and economic data on a county- or municipal-level (Ewing et al., 2002; Pendall et al., 2000; Fulton et al., 2000; Burchell and Shad, 1999; Orfield, 1997). These approaches vary in spatial resolution but generally employ a unit of analysis that is too course to distinguish spatial details of urban growth that may be useful or necessary to effectively characterize urban sprawl. For example, low density is often identified as one of the characteristics of sprawl. However, a unit of analysis such as a census tract may contain a significant mixture of non-residential land use and open space that would result in an inaccurate average density for the census tract as a whole. It is an ecological fallacy to assume that site-specific housing density within the tract can be determined by the average housing density of the whole tract (Openshaw, 1984). In order to have meaningful measure of sprawl, a spatial resolution smaller than a census track is needed for adequate urban structural analysis.

Recent work has made progress on identifying the spatial characteristics of sprawl as identified by indicators focusing on urban form. Torrens and Alberti (2000) suggest a number of spatial metrics that could be developed for identifying and quantifying sprawl. Most recently there has been some progress on developing metrics of sprawl at a micro-level of a census block group (Song and Knaap, 2004) and the individual housing unit scale (Hasse and Lathrop, 2003). This paper builds on this recent work by focusing on the accessibility of individual residential units to a set of common community destinations.

Defining Spatial Metrics Based on Problematic Characteristics of Sprawl

Spatial metrics of sprawl must be designed around commonly accepted criteria. Objectivity is needed because the term *sprawl* is often vague, politically inciting and often used in a rhetorical manner to criticize development unwanted by certain stakeholders. Within the literature the term urban sprawl has itself sprawled. Burchell et al., (1998) is widely cited in the sprawl literature and presents a working definition of sprawl as "low density residential and nonresidential intrusions into rural and undeveloped areas, and with less certainty as leapfrog, segregated, and land consuming in its typical form." Reid Ewing (1997) offers a summary of 17 references to sprawl in the literature as being characterized by "low density development, strip development and/or scattered or leapfrog development." Ewing uses a transportation component to help define sprawl. He suggests that the lack of non-automobile access is also a major indicator or sprawl. Downs (1998), the Florida Growth Management Plan (1993) and Sierra Club (2004) each have succinct definitions of sprawl that suggest that some of the most significant problematic consequences of sprawling development are the heavy reliance on the automobile and lack of pedestrian, bicycle and public transit accessibility.

Accessibility (or lack of it) emerges as one demonstrably problematic characteristic of sprawl this is spatially quantifiable within a GIS environment. The predominance of the automobile as the primary (and in many cases) only mode of transportation results in more vehicle miles traveled and by implication more impact to the environment. Furthermore, development that is exclusively dependent upon the automobile also has social implications as the dispersed location of housing, community services, nodes of commerce and employment segregates those who do drive from those who can't or choose not to. Sprawling land use patterns seem to spread all growth haphazardly throughout a landscape. There is little "sense of place" as destinations of community activity are not situated in sensible relation to each other nor to new urban development. This is especially significant when a tract of new residential development is located at a large distance from important community centers such as schools, police, fire and rescue, recreational facilities, etc. The result is a land use pattern that is energy and land inefficient, creates a lack of definable town identity, results in longer response times for emergencies; and diminished sense of community. A sprawl grading methodology that characterizes urban form by measuring road distance between residential housing and important community nodes provides an objective indicator based on tangible undesirable consequences of sprawling development growth.

METHODOLOGY

The sprawl accessibility index developed in this paper measures the distance from each housing unit within a study area to a selected set of important community nodes including schools, emergency service stations, grocery stores, post offices, public transit, municipal buildings and parks. This measure summarizes the average road network distance from new housing units to each of these community nodes, the locations of which were identified by use of county maps, in-situ observation, and orthophotography. The community node data layer was created as a point layer shapefile through on-screen digitizing of othophotography.

The location of residential housing units was created county-wide following a method of intersecting digital land use data with a property parcel layer and extracting the centroid of intersection between residential land use and property parcels (see Hasse and Lathrop, 2003 for detailed methodology). With the residential units and community nodes defined as individual point shapefiles, the distance between each house and each community node could then be calculated within a raster GIS environment by converting the roads layer to a grid and utilizing a "cost-distance" function between housing and community nodes on the gridded road network. Since the point location of each housing unit was usually offset from the gridded road network, an allocation grid was added to a distance grid from the road network (Upchurch et al., 2004) to produce a surface of distance from each community node via the straight-line path of the housing location to the road network and then to the community node. The value of each community node distance surface grid could then be assigned back to the housing unit point file utilizing a grid to point operation resulting in a calculated road distance value to the nearest of each of the set of community nodes. The distance values for each of the community nodes were then averaged for each housing unit.

The community node accessibility methodology was performed on Hunterdon County, New Jersey. Over 43,000 residential units were located county wide utilizing digital parcels intersected with digital land use data. Since the land use data contained multidate information for the year 1986 and 1995, the housing units were able to be segregated into pre 1986 and 1986-1995 categories. Figure 1 portrays the housing unit locations county-wide with the housing units as grey dots and the community node centers as black dots.

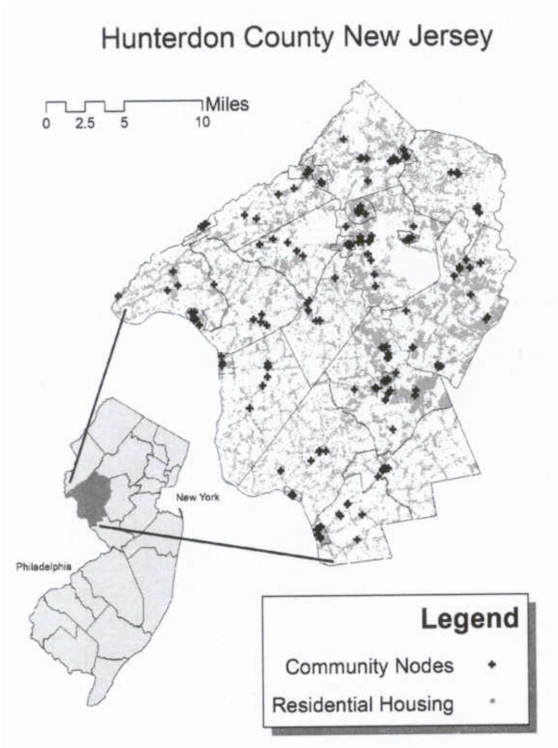

Figure 1. Location of residential housing and community nodes in Hunterdon County, New Jersey (1995).

The community node distance methodology entails creating a cost-distance grid for each community node type using a rasterized county road layer as the cost grid and the selected community node point layer as the source. This produced an output where the distance to each community is generated along the gridded road cells. However, most housing units are not directly on a road. In order to compensate for this, the roads distance grid was distributed to a surface using an allocation operation added to a straight-line distance operation from the road layer. This created a surface which represents the straight-line distance from any point to the nearest road and then along the road to the closest community node of each type. Figure 2 provides a zoom in to an area near the County Seat of Flemmington with the housing units depicted over the surface layer representing average distance to community nodes via the road network.

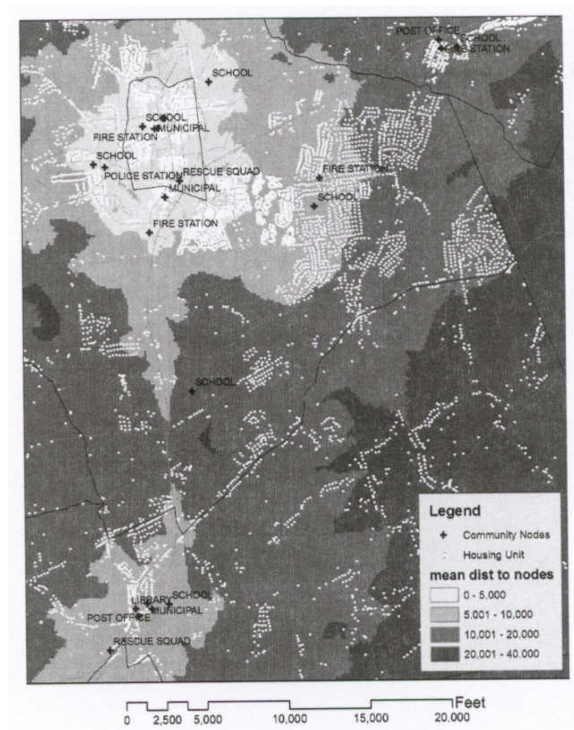

Figure 2. Close-up of housing units over average distance surface nodes near the town of Flemmington (1995)

Developing a Sprawl Grading System Based on Accessibility

A sprawl-grading system based on accessibility must incorporate measures based on how likely a resident of a given housing unit will utilize modes of transportation other than the automobile. For example, for a unit of housing to be least sprawling it would ideally be situated in a location easily accessible to community nodes by walking. Housing that is only accessible to community nodes via excessive automobile travel would epitomize sprawl. Housing that was reasonably accessible to community nodes via bicycle access would be somewhere in between sprawl and smart growth.

Table 1 summarizes the ease of accessibility via walking, bicycle and automobile based on the distance that a person might reasonably walk, cycle or drive in 10, 20 and greater than 20 minutes. The travel times and distances were based on a walking speed of 2.8 mph, biking speed of 5.7 mph, and driving speed of 22.7 mph. The speeds of travel were derived by the authors by timing reasonably paced travel via each mode with some slight adjustments to facilitate dovetailing of travel distance categories between each mode as well as to round numbers to manageable intervals. Clearly the speeds at which people walk, bike and drive will differ depending on the individual as well as the site-specific conditions.

Nevertheless, the categories proposed in Table 1 represent reasonable average speeds and distances for *Easy*, *Moderate* and *Poor* categories of accessibility via each mode. The longer the travel time for any given mode of travel the less likely that mode will be employed.

The accessibility distances for categories of sprawl are thus defined. Residential units that are located less than 2,500 feet on-average to community nodes (approximately ½ mile) are easily accessible by walking and therefore considered *Walking Smart Growth*. Residential units that are located between 2,500 and 5,000 (approximately a mile) on average from community nodes are moderately accessible by walking and easily accessible by bicycle therefore exhibit signs of *Bicycle Smart Growth Bike*. Units that are between 5,000 feet and 10,000 feet are moderately accessible by bicycle and easily accessible by automobile are considered *Suburban Sprawl*. Units that are between 10,000 and 20,000 feet from community nodes are only reasonably accessible by automobile and considered *Rural Sprawl*. Units that are over 20,000 feet from community nodes are located deep within the environs of the region and considered *Excessive Sprawl* (see table 2).

Table 1. Accessibility Categories Based On Mode of Travel and Distance.

Mode of Travel	*Ideal*	*Easy*	*Moderate*	*Poor*
Pedestrian	0-5 minutes 0-1,250 ft ideally accessible pedestrian	6-10 minutes 1,251-2,500 ft easily accessible pedestrian	11-20 minutes 2,501- 5,000 ft moderately accessible pedestrian	>20 minutes > 5,000 ft poorly accessible pedestrian
Bicycle	0-5 minutes 0 – 2,500ft ideally accessible bicycle	6-10 minutes 2,501 – 5,000ft easily accessible bicycle	11-20 minutes 5,001 – 10,000 ft moderately accessible bicycle	>20 minutes > 10,000 ft poorly accessible bicycle
Automobile	0-5 minutes 0 – 10,000 ft ideally accessible automobile	6-10 minutes 10,001 – 20,000 ft easily accessible automobile	11-20 minutes 20,001 – 40,000 ft moderately accessible automobile	>20 minutes > 40,000 ft poorly accessible automobile

Table 2 Sprawl Grading Categories Based on Accessibility to Community Nodes.

Grade	Criteria	Label
A	0 – 2,500 feet on average to community nodes	Walking Smart Growth
B	2,501 - 5,000 feet on average to community nodes	Bicycle Smart Growth
C	5,001 – 10,000 feet on average to community nodes	Suburban Sprawl
D	10,001 – 20,000 feet on average to community nodes	Rural Sprawl
F	> 20,000 feet on average to community nodes	Excessive Sprawl

RESULTS

The average community node distance from residential unit to community nodes for all units was 11,368 ft. This means that each housing unit county-wide exist at an average of 2.2 miles via the road network to any given community node. On average, Hunterdon County residential housing scores a "D" for sprawl as measured by accessibility. Figure 3 provides a graph of the percentage of units that occurred within each sprawl category. Figures 4-A through 4-F map the location of housing units for each sprawl category.

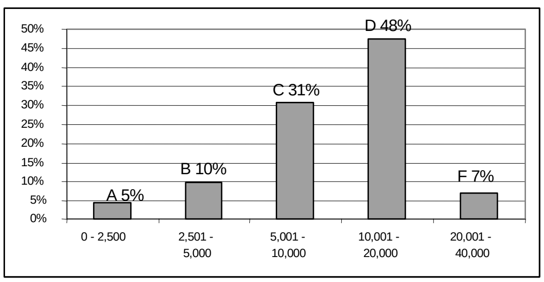

Figure 3. Percentage of county housing units within each sprawl category.

Breaking the housing into pre 1986 versus 1986 – 1995 units reveals the change in accessibility during recent decades. The results demonstrate that as a percentage of total units, pre 1986 housing performed better than 1986–1995 housing for the categories of *Walking Smart Growth* and *Rural Sprawl*. However, the more recent time period of growth actually had a greater percentage of new homes built in the *Bicycle Smart Growth* Category then did the pre-1986 housing stock. Overall, the average distance to community node pre 1986 was 11,272 feet versus the 1986 – 1995 average of 11,714 feet representing a 3.9% increase in average distanceto community nodes over the 9 year period of growth. Although it must be considered that this measure assumes the current set of community nodes which may not be accurate for the years preceding 1986.

DISCUSSION

The sprawl grading system presented in this paper represents a new approach to quantifying urban form utilizing road accessibility, overcoming a number of previous limitations to sprawl analysis. However, a number of complications were encountered with the methodology as employed. Hunterdon County is a once rural region whose location (within a 1 hour commute to both Philadelphia and New York) has led to a dramatic increase in development pressure over the past several decades. Much of the pre 1986 residential housing is associated with the older, more compact rural towns and villages whereas much of the more recent development is largely serving a bedroom community function for both metropolitan areas. Since the county has traditionally been a rural/agricultural area there is little available infrastructure such as public water and sewer necessary for creating the compact communities that would mitigate sprawl. Private well and septic necessitates the spreading of residential development into bigger lots over larger areas. The important point is that evaluating the degree of sprawl for any locality should be considered within the context of its own juxtaposition. Sprawl for one community may not be sprawl for another. However, by measuring an empirical factor such as accessibility to schools and fire/rescue, etc., important fiscal, safety and environmental conditions related to sprawl can be directly evaluated for any proposed development and compared between any two communities. The word sprawl need not even be used.

One important limitation for this pilot study of Hunderton County was the lack of data for adjacent counties. In order to calculate true average

Figure 4 – A & B. *Smart Growth* housing units.

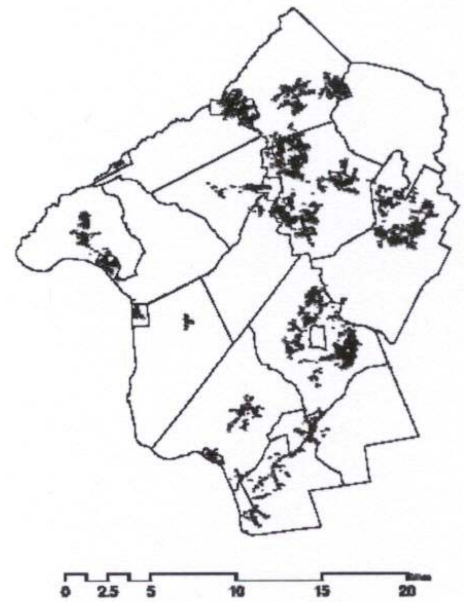

Figure 4 – C. Suburban Sprawl housing units.

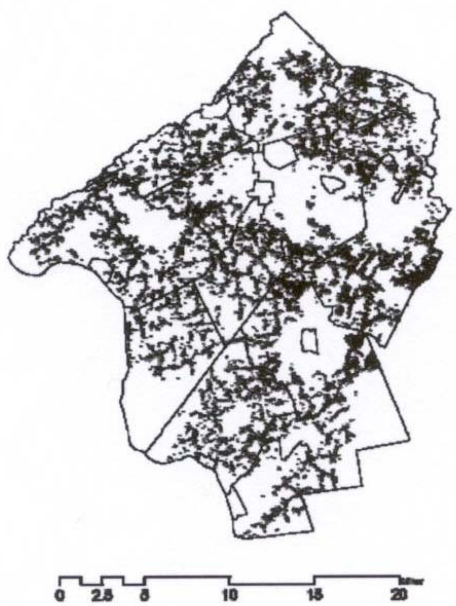

Figure 4-D. *Rural Sprawl* housing units

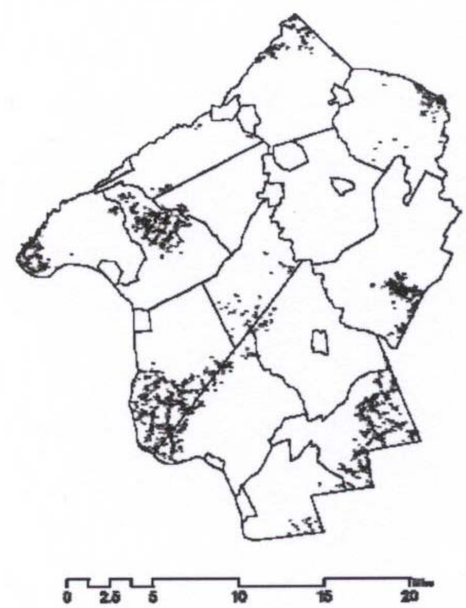

Figure 4 – F. *Excessive Sprawl* housing units.

accessibility distance to the nearest community centers, community centers across the county boundaries should be considered. The lack of adjacent data for this study probably resulted in housing units near the county boundaries being assigned a more-sprawling grade than was warranted. However, in the Case of Hunterdon County, this boundary issue is lessened by the fact that more than half the county boundaries consist of significant rivers with few crossing points (including the Delaware River on the western border). Nonetheless, for the most accurate results, community nodes should be delineated within a 5 mile buffer outside the study area corresponding to the excessive sprawl distance.

Another important factor is the assumption made when utilizing the road network for the pedestrian and bike network. This is an imperfect model because many roads will not have adjacent sidewalks or sufficiently safe lanes for bicycles making the use of these roads less likely for non-automobile modes of travel. People will not travel to a destination via foot or bike regardless of how close it is if there is not a safe corridor for travel. Likewise, the methodology as presented does not consider other bicycle and pedestrian pathways that are not always situated parallel to roadways which could give greater accessibility to non-automobile modes of travel than is reflected utilizing the road network alone. Furthermore, the methodology presented here does not properly handle the overpasses and barriers presented by major limited access highways. These are some of the limitations of utilizing a grid-based approach to network distance. The strength of the grid based approach is that it allows for off-network distances to be incorporated into the distance measure (Upchurch et al., 2004).

While these strengths and weaknesses of a grid-based approach are significant, they may be overcome in future analysis by incorporating a combined vector/grid approach to measuring accessibility. Overcoming the limitations of measuring road network accessibility will provide an even more robust indicator of sprawl because accessibility not only indicates travel mode and travel time requirements but also performs as a good proxy for the dispersed and dis-coordinated patterns of land use associated to sprawl. Eventually these technical issues will be addressed through more comprehensive data development that includes sidewalks and non-auto pathways as well as vector-based distance measures over the road network that can compensate for issues such as overpasses, etc.

Interpreting the results of this case study as an indicator of sprawl reveals the sprawling nature of development within Hunterdon County. Only 15% of the housing units within the county are indicated to be one of the two categories of A and B *Smart Growth* whereas 85% were indicated as a category of *Sprawl*. This suggests that only 15% of Hunterdon County households live in a location in which it is reasonable to walk or bike for common daily activities. The units are all located within or adjacent to 5 older towns which have their community nodes organized within a town center.

The category labeled C- *Suburban Sprawl* accounts for 31% of the housing units countywide representing housing location 1 to 2 miles on average to community nodes. This category of sprawl indicates a pattern of housing somewhat near existing town centers but far enough away that it is poorly accessible to walking and only moderately accessible to biking. The largest category of sprawl representing 48% of the residential units was D- *Rural Sprawl* with an accessibility distance between 10,000 and 20,000 feet on average to community nodes. This means that nearly half of county residents must travel between 2 and 4 miles to any community node, a distance that necessitates an automobile for all but the more ardent athlete. Another 7% make up the F- *Excessive Sprawl* category with accessibility measures over 4 miles average distance. These households will likely contribute the most vehicle miles traveled within the county. Hunterdon County clearly exemplifies a pattern of sprawling development all too common in recent decades throughout New Jersey and the nation as a whole.

CONCLUSION

Measuring spatial characteristics of urban form such as accessibility provides one with a quantifiable means of capturing the elusive and rhetorical concept of sprawl. The measure developed in this paper demonstrates that such empirical indicators can be successfully produced at the microscale of individual housing units. By focusing specifically on the undesirable and problematic characteristics of development that most stakeholders can agree should be avoided, such measures provide meaningful information to land managers and other stakeholders. Road accessibility is a particularly strong indicator of sprawl and smart growth because it captures a number of the diverse traits of sprawl into one metric. Sprawl is not only low density but dispersed in nature and not well connected to other elements of the built landscape. The accessibility measure captures the leapfrog, and segregated dimensions of sprawl because mixed use and compact land uses would likely result in closer community node measures. Further work is needed to determine the correlation between community node accessibility and other characteristics of sprawl and smart growth in order to establish these relationships. Research is also needed to refine and standardize the metric so that it can be utilized to compare development patterns in different locals and at different scales. Eventually measures such as these may lead to a sprawl rating system that could be utilized for a developing performance standard to encourage urban growth to follow the principles of smart growth and avoid the undesirable consequences of sprawl.

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